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PATENT SPECIFICATION

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(19)

(54) IMPROVEMENTS IN OR RELATING TO CLOSED CYCLE GAS TURBINE SYSTEMS

(71) We, THE ENGLISH ELECTRIC COMPANY LIMITED, of 1, Stanhope Gate, London, W1A 1EH, formerly of Bush House, Aldwych, London, WC2B 4QJ, a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to closed cycle gas turbine systems, and particularly to a closed cycle gas turbine system integrated with a nuclear reactor.

Such a gas turbine integrated in a nuclear reactor is driven by gas, e.g. helium or carbon dioxide heated to a high temperature by the nuclear reactor core, and is operative to drive a load, for example an alternator. Upon loss of load the turbine rotor quickly speeds up, and to prevent it reaching an excessive speed, i.e. overspeed, at which damage to the turbine may occur, it is necessary to prevent further supply of energy to the turbine.

On loss of load in conventional open cycle gas turbines, it is often sufficient, in order to prevent overspeed, to cut off the fuel supply, thereby preventing further production of energy. Alternatively, the gas may be bypassed around the turbine. However, a closed cycle gas turbine driven by helium has considerably smaller rotor blades than conventional open cycle turbines, and therefore the rotor has a much lower inertia. Thus, overspeed is reached far more quickly. Furthermore, the nuclear core is continually supplying heat energy to the gas and this energy must be dumped since excessively high gas temperatures may cause damage to the turbine. Thus it is necessary to act extremely quickly to shut down the turbine.

According to the present invention in one aspect, a closed cycle gas turbine system includes a power turbine having a gas inlet through which a heated gas supply is arranged to be fed to the turbine and a gas outlet from which gas is arranged to be exhausted from the turbine, and the turbine being operable to drive a load, the system including also a bypass valve arrangement which upon loss of load is operative to prevent further exhaust of gas from the gas outlet, to feed a part of the gas supply to the gas outlet so that, at least initially, it flows to the turbine in a reverse direction thereby to rapidly destroy the pressure drop across it, and to feed the remainder of the gas supply to a cooling means.

Preferably the system includes a further turbine also having a gas inlet and a gas outlet, this second turbine being operable to drive a compressor, and the gas outlet from this compressor-driving turbine being connected to the gas inlet of the power turbine so that the exhaust gas from the compressor-driving turbine constitutes the gas supply for the power turbine, and an auxiliary valve arrangement which is operative in conjunction with the bypass valve arrangement to divert the gas supply for the compressor-driving turbine to the cooling means when the gas supply to the compressor-driving turbine is of excessively high temperature.

Preferably the resistance to gas flow through the cooling means is the same as the resistance to gas flow through the power turbine, so as to prevent overspeed of the compressor-driving turbine occurring when the bypass-valve arrangement is operated to isolate the power turbine.

According to a preferred feature of the invention the compressor-driving turbine gas outlet is connected by a first duct to the power turbine gas inlet so that under normal conditions the gas exhausted from the compressor-driving turbine passes along the first duct to the power turbine gas inlet, and the bypass valve arrangement includes a first valve arranged in a side duct connecting at one end with the first duct and at the other end with the cooling means, a

second valve arranged in the power turbine outlet duct and a third valve arranged in a second duct connecting the first duct with the gas outlet of the power turbine, so that, on the first and third valves being open and the second valve being closed, part of the gas exhausted from the compressor turbine gas outlet passes through the first valve to the cooling means and a second part flows through the third valve to the power turbine gas outlet to rapidly destroy the pressure drop across it, the closure of the second valve preventing exhaust of gas from the power turbine gas outlet.

Preferably all valves are actuated to open or close simultaneously, and the second and third valves are mechanically interconnected.

According to another preferred feature of the inventon the second valve comprises a poppet valve member carried on a stem, which is slidable to move the valve member towards and away from a valve seating arranged around an end aperture of a duct extending around the stem and valve member, and the third valve comprises a cylindrical valve member mechanically connected to the stem and slidable with it, so as to uncover and cover an annular port or ring of ports provided in the duct wall.

Preferably also the by-pass valve incorporates an inner hollow cylindrical valve member having a closed valve position, in which one end seats on a valve seating provided on an outer valve sleeve surrounding the inner valve member, and a face of a flange provided around the periphery of the opposite end of the inner valve member seats on a seating provided by a co-operating face of an inwardly directed flange on the outer valve sleeve, the inner cylindrical valve member being slidable axially to uncover or cover a port or ports provided in the wall of the outer valve sleeve.

Such an arrangement has the advantage that the total area of the surfaces of the inner cylindrical valve member which engage the valve seatings can be kept small, resulting in very low axial forces from gas pressure on the inner valve member and the operating mechanism therefor, when opening or closing the valve.

Preferably there is little difference between the area of the seating surface at one end of the inner valve member and that at the other end of the member.

Such a valve has very good sealing properties since the seatings can be accurately made. Moreover differential thermal movement will be small and a satisfactory seal will be maintained even under high temperature conditions.

The inner cylindrical valve member is conveniently supported and guided by spokes carried by a central operating spindle which is axially slidable in at least one bearing bush fixed in relation to the valve sleeve.

An embodiment of the invention will now be described by way of example only with reference to the accompanying drawings, in which:—

Figure 1 is a schematic diagram of a closed cycle gas turbine system incorporating a bypass valve arrangement according to the present invention;

Figure 2 is a sectional view of a nuclear reactor pressure vessel wall in which parts of the system shown in Figure 1, including the bypass valve arrangement according to the invention, is housed;

Figure 3 is an enlarged sectional view of valves of the bypass valve arrangement shown in Figure 2; and

Figure 4 is an enlarged sectional view of an auxiliary valve shown in Figure 1.

Referring now to Figure 1, a closed cycle gas turbine system integrated with a nuclear reactor includes a reactor 1 used to generate heat which is extracted by helium gas from the reactor 1 along a gas path 2, to a high pressure turbine 3; and the gas exhausted from the turbine 3 is fed via a gas path 4 to a low pressure turbine 5 which drives an alternator 6. The gas exhausted from the low pressure turbine 5 passes along a gas path 7, through a recuperator 8, where heat is transferred from the exhaust gas to the inlet gas being fed to the reactor, and through a pre-cooler 9 where the gas is further cooled before passing through first and second stage compressors 10 and 11, connected by an inter-cooler 12 and driven by the high pressure turbine 3. From the second stage compressor 11 the gas passes through the recuperator 8 where it is heated as described above, and is fed back to the nuclear reactor 1 for reheating. The cycle around which the gas passes is a conventional closed cycle system and will not be described further.

Upon loss of load on the turbine 5, e.g. by failure of the alternator 6 or open-circuiting of its output, it is necessary to prevent further gas from being supplied to the turbine 5, thereby to prevent it from reaching overspeed conditions in which damage to the turbine 5 may occur. This is achieved by providing a bypass valve arrangement including valves12, 13 and 14.

The valve 12 is situated in a side gas path 15 connecting at one of its ends with the gas path 4, this gas path 4 being connected at one end with a gas outlet 16 of the turbine 3 and at the other end with a gas inlet 17 of the turbine 5. The other end of the gas path 15 is connected to a heat rejection cooler 18 which exhausts via the gas path 7 to the recuperator 8.

The valve 13 is connected in the gas path 7 between the exhaust of the cooler 18 and the gas outlet 19 of the turbine 5 and the valve 14 is arranged in a gas path 20 connecting at one end with the gas path 4 intermediate the high pressure turbine outlet 16 and the junction of the side gas path 15 with the gas path 4, and at the other end with the gas path 7 intermediate the valve 13 and the low pressure turbine gas outlet 19.

When loss of load occurs a sensor (not shown) actuates the valves 12 and 14 to open and the valve 13 to close. Closure of the valve 13 prevents further exhaust of gas from the outlet 19 of the turbine 5 along the path 7. The effect of the other valves is as follows; a first part of the gas exhausting from the outlet 16 of the turbine 3 flows along the gas path 20 through the valve 14, and into the outlet 19 of turbine 5, whilst a second part of the gas flows along the gas path 4, along the side gas path 15 through the valve 12, and into the heat rejection cooler 18 where it is cooled by cooling water entering the heat rejection cooler 18 along a coolant path 24. The first part of the gas which enters through the outlet 19 of the turbine 5, flows in a reverse direction into the turbine 5 thereby destroying the pressure drop across it and assisting in rapidly decelerating its rotor.

The resistance to gas flow through the cooler 18 is arranged to be substantially the same as the resistance to flow through the turbine 5 under load. Thus overspeed of the turbine 3 is prevented, on the valves being switched, even though the supply of gas to an inlet 21 of the turbine 3 along the gas path 2 from the reactor 1 is maintained.

Valves 12, 13 and 14 are also operable, in conjunction with an auxiliary valve 22, in response to signals from a sensor or sensors for detecting the occurrence of overspeed of the turbine 3 and/or excessively high temperatures in the gas being supplied to the turbine 3, to prevent possible damage to the turbines. The valve 22 is arranged in a gas path 23 connecting at one end with the inlet 21 of the turbine 3, and at its other end with the gas path 7 at the valve 13, such that with the valve 13 closed, gas may flow along the gas path 7 towards the outlet 19 of the turbine 5. Thus, in response to a signal from a sensor for detecting either the occurrence of overspeed conditions in the turbine 3 or from a sensor detecting the occurrence of excessively high temperature of the gas supply, or both, valves 12, 14 and 22 are opened and valve 13 is closed, valves 12, 13 and 14 receiving their respective actuating signals either prior to or simultaneously with the signal to open valve 22, thus allowing gas flowing along the gas path 2 to be bypassed around the turbine 3 and along the gas path 23 into the gas path 7, from which it is exhausted via the gas path 20 through the valve 14 in to the gas path 4. The gas is then passed along the gas path 15 through the valve 12 into the heat rejection cooler 18.

Referring now to Figure 2 the gas is fed from a reactor core (not shown) via a duct 29 and an annular flow space 30, the turbine 3 being arranged within a bore 31 in a pressure vessel wall 32 of the reactor 1. Vertically below the turbine 3 the turbine 5 is arranged in an L-shaped sleeve 33 mounted in the bore 31, and a poppet valve member 34 is fixed to the end of a stem 35 slidably mounted in a sleeve 37, so that sliding of the stem, effected by a crank mechanism indicated generally at 36, in response to opposite longitudinal movements of control rods 38 and 39, causes the valve member 34 (Figures 2 and 3) to engage with or disengage from a valve seating 40 provided in the bore 41 in the pressure vessel wall 32) as viewed in Figure 2), thereby to open or close the bore 41. The valve member 34 and seat 40 constitute the valve 13.

The bore 41 opens into a second bore 42 in the pressure vessel wall 32, in which bore 42 is provided the recuperator 8. The heat rejection cooler 18 is also mounted in the bore 42 but isolated from the recuperator 8 by sealing walls 43.

The construction of the valve 14 will be more easily understood with reference to Figure 3, which also shows the valve 13 on a larger scale. The valve 14 is constituted by a cylindrical sleeve member 44 fixed on spokes 45 extending from the rear face of the valve member 34. The sleeve member 44 is provided at one end with a shoulder 46, and is slidable with the valve member 34 so that the shoulder 46 can be engaged or disengaged from a seat 47, arranged on one side of an annular port or ring of ports 48 in the sleeve 33, whilst the other end 49 of the sleeve engages or disengages on a seat 50 on the other side of the port or ports 48. A clearance is provided between the outer peripheral surface of the sleeve member 44 and the adjacent inner surface of the sleeve 33, so that there is no metal-to-metal contact between the two as the sleeve member 44 slides to cover or uncover the port or ports 48.

As will also be seen in Figure 3, the valve member 34 is mounted on the stem 35 by a spherical bearing indicated generally at 51 so that it seats correctly against the seat 40 without risk of bending of the stem 35. Furthermore, the sleeve 37 in which the stem slides is mounted concentrically in the sleeve 33 on fixed radial vanes 52 at its end adjacent the valve member 34, and in a bearing 53 at its other end. Heat insulation

54 is provided on the surfaces of the sleeve 33

Referring again to Figure 2, a connecting bore 61 connects the bore 31 with region of the bore 42 housing the heat rejection cooler 18. This bore 61 houses the valve 12, which may be opened or closed to connect or disconnect the bores 31 and 42. The valve 12 is constituted by a cylindrical tube 62 mounted in the bore 61, and having an annular port or ring of ports 63, and a cylindrical sleeve member 64. The sleeve member 64 is secured to the ends of spokes 65 fixed to, and extending radially from, a shaft 66 which is slidably mounted at one end in a journal 67, provided in a closure plate of the tube 62, and at the other end in a journal 68 fixedly mounted by spokes 69, concentrically of the sleeve 62. The shaft 66 is actuated to slide by a crank mechanism indicated generally at 70 in response to opposite longitudinal movements of control rods 71 and 72, thereby to cause the cylindrical sleeve member 64 to cover or uncover the port or ports 63.

The annular flow space 30 is connected to the bore 33 by a connecting bore 73, adjacent the seating 41 of the valve 13, and the valve 22 is located at the junction of the bore 73 and the annular flow space 75.

The valve 22 is more clearly shown in Figure 4, and comprises a tube 76 mounted centrally in the annular flow space 75, and having an annular port or ring of ports 77. A cylindrical sleeve member 78 is fixed on the ends of spokes 79, fixed to and extending radially from a shaft 80, which is slidably mounted at one end in a journal 81, provided in an end closure plate 82 for the tube 76, and at the other end in a journal 83, fixedly secured concentrically in the tube 76 by spokes 84.

The sleeve member 78 is provided at one end with a shoulder 85, which is engageable with a seat 86 provided at one side of port or ports 77, whilst the other end of the sleeve member 78 is engageable with a seat 87 at the other side of the port or ports 77; thus as the shaft 80 slides in the journal, the sleeve member 78 slides to cover or uncover the port or ports 77, there being little difference between the areas of those surfaces of the member 78 which engage the two valve seats 86, 87.

A clearance is provided between the outer surface of the sleeve member 78 and the inner surface of the tube 76, so that as the sleeve slides to cover or uncover the port or ports 77, there is no metal to metal contact between the two surfaces.

Such an arrangement has the further advantage that since the total area of the surfaces of the sleeve member 78 which engage the seats 86, 87 are small the gas pressure exerts only a low axial force on the member 78 when opening and closing the valve, so that the operating mechanism for the member need be of simple and light construction.

The shaft 80 is actuated to slide in response to opposite longitudinal movements of a pair of control rods 90 via a crank mechanism indicated generally at 91. A closure plate 92 is provided to seal the bore 73 from the bore 42.

Under normal operating conditions, i.e. with valves 12, 14 and 22 closed, valve 13 open, and with the turbine driving the alternator 6, wiich although not shown in Figure 2 is vertically mounted beneath the turbine 5 on a common shaft therewith, the gas flows along the duct 29 into the annular flow space 30, through the turbine 3, into the bore 31. It then passes around the outside of the sleeve 33 to the bottom of the bore 31 (as viewed in Figure 2) and then upwardly through the turbine 5, and through the valve 13 into the bore 42, from where it is passed into the recuperator 8. Although no gas is passed to the heat rejection cooler 18 during normal operation, cooling water is continually supplied to it. Graphite blocks 93 or any other suitable heat absorbing blocks are provided at the gas entry zone of the heat rejection cooler, to minmize the effect of thermal shocks of hot gas entering the cooler 18 when this occurs as explained below.

Upon failureof the alternator or on loss of the alternator load, the sensor produces a signal which is operable, via means not shown, to move the rod 39 downwardly and rod 38 upwardly as viewed in Figure 2 so that the stem 35 slides to move the valve member 34 to engage the seat 40, and the cylindrical valve member 44 to uncover the port or ports 48. Simultaneously the control rods 71 and 72 are actuated to move downwardly and upwardly respectively (as viewed in Figure 2), by means not shown, so that the stem 66 slides from right to left (as viewed in Figure 2) and the cylindrical sleeve member 64 uncovers the port or ports 63

When these valves are actuated, part of the gas exhausting from the turbine 3 into the bore 31 flows through the open port or ports 48, and downwardly to the turbine 5 (i.e. in a reverse direction). This gas immediately increases the low pressure existing in the outlet region of the turbine 5, thus destroying the pressure drop across the turbine 5, and rapidly decelerating the turbine rotor. The other part of the gas flows into the bore 61 and is exhausted directly through the open port or ports 63, past the graphite blocks 93 into the heat rejection cooler 18.

The gas pressure acting on the poppet valve member 34 helps to close the valve

member 34 against the seat 40. The surface area of the valve member 34 on which the gas pressure acts to help closure of the valve member 34 is considerably greater than the surface area of the radially extending face of the sleeve member 44. Thus, initially a larger force is applied by the gas in the direction of sliding of the stem 37, to help closure of the valve member 34 than the force opposing such closure. As soon as the sleeve member 44 is removed from its seat 50, gas pressure is applied to both radially extending faces of the sleeve member 44, and thus the forces in the direction of movement of the sleeve member 44 are virtually balanced out.

Should overspeed of the turbine 3 occur, or the heat of the gas being supplied along the duct 29 be excessive, or both, the or each sensor for detecting such a condition produces a signal which is operable via means not shown to open valves 12 and 14 and to close valve 13 as hereinbefore described, and to cause the control rods 90 to actuate the stem 80 to slide from left to right and uncover the port or ports 77.

Thus the gas flowing into the annular flow space 30 from the duct 29 is exhausted via the open ports 77 into the bore 73. This gas then flows from the bore 73 via the annular port or ports 74, and the annular port or ports 48, into the bore 31 from where it is exhausted into the heat rejection cooler 18, via the open port or ports 63.

Gas entering the heat rejection cooler 18 is exhausted in a cooled state via a perforated plate 95 into the bore 42 and thence into the recuperator 8 to complete the usual closed gas cycle.

A high rate of heat rejection from the gas is possible by allowing the cooling water entering the heat exchanger 18 to boil.

Such a system allows rapid shut-down of one or both of the turbines without shutting off the gas supplied from the reactor core via the inlet duct 29. The use of sleeve members in the valves helps to achieve this end, since the gas pressure acts only on the radially extending faces of the sleeve member. Furthermore, as soon as the sleeve member leaves its seating, the radially extending faces at both ends are subjected to the gas pressure, thus virtually balancing out the forces applied to the sleeve member along its line of movement.

WHAT WE CLAIM IS:—

1. A closed cycle gas turbine system including a power turbine having a gas inlet through which a heated gas supply, after passing through a compressor-driving turbine is arranged to be fed to the power turbine and a gas outlet from which gas is arranged to be exhausted from the power turbine, the power turbine being operable to drive a load, the system including also a bypass valve arrangement which upon loss of load is operative to prevent further exhaust of gas from the gas outlet, to feed a part of the gas supply to the gas outlet so that, at least initially, it flows to the power turbine in a reverse direction thereby to rapidly destroy the pressure drop across it, and to feed the remainder of the gas supply to a cooling means.

2. A closed cycle gas turbine system according to Claim 1 including an auxiliary valve arrangement which is operative in conjunction with the said bypass valve arrangement to divert the gas supply for the compressor-driving turbine to the cooling means when the gas supply to the compressor-driving turbine is of excessively high temperature.

3. A closed cycle gas turbine system according to Claim 1 or 2 wherein the cooling means is so arranged that the resistance to gas flow through it is substantially the same as the resistance to gas flow through the power turbine, so as to prevent overspeed of the compressor-driving turbine occurring when the bypass-valve arrangement is operated to isolate the power turbine.

4. A closed cycle gas turbine system according to Claim 1, 2 or 3 wherein the compressor-driving turbine gas outlet is connected by a first duct to the power turbine gas inlet so that under normal conditions the gas exhausted from the compressor-driving turbine passes along the first duct to the power turbine gas inlet, and the bypass valve arrangement includes a first valve arranged in a side duct connecting at one end with the first duct and at the other end with the cooling means, a second valve arranged in the power turbine outlet duct, and a third valve arranged in a second duct connecting the first duct with the gas outlet of the power turbine, so that, on the first and third valves being open and the second valve being closed, part of the gas exhausted from the compressor turbine gas outlet passes through the first valve to the cooling means and the second part flows through the third valve to the power turbine gas outlet to rapidly destroy the pressure drop across it, and the closure of the second valve preventing exhaust of gas from the power turbine gas outlet.

5. A closed cycle gas turbine system according to Claim 4 wherein opening of the first and third valves and closure of the second valve is arranged to take place substantially simultaneously.

6. A closed cycle gas turbine system according to Claim 5 wherein the second and third valves are mechanically interconnected.

7. A closed cycle gas turbine system according to Claim 6 wherein the second

valve comprises a poppet valve member carried on a stem, which is slidable to move the valve member towards and away from a valve seating arranged around an end aperture of a duct extending around the stem and valve member, and the third valve comprises a cylindrical valve member mechanically connected to the stem and slidable with it, so as to uncover and cover an annular port or ring of ports provided in the duct wall.

8. A closed cycle gas turbine system according to Claim 1 wherein the by-pass valve incorporates an inner hollow cylindrical valve member having a closed valve position, in which one end seats on a valve seating provided on an outer valve sleeve surrounding the inner valve member, and a face of a flange provided around the periphery of the opposite end of the inner valve member seats on a seating provided by a co-operating face of an inwardly directed flange on the outer valve sleeve, the inner cylindrical valve member being slidable axially to uncover or cover a port or ports provided in the wall of the outer valve sleeve.

9. A closed cycle gas turbine system according to Claim 8 wherein there is little difference between the area of the seating surface at one end of the inner valve member and that at the other end of the member.

10. A closed cycle gas turbine system according to Claim 8 or 9 wherein the inner hollow cylindrical valve member is supported and guided by spokes carried by a central operating spindle which is axially slidable in at least one bearing bush fixed in relation to the valve sleeve.

11. A closed cycle gas turbine system substantially as shown in and as hereinbefore described with reference to Figures 1 to 4 of the accompanying drawings.

12. A nuclear reactor incorporating a closed cycle gas turbine system according to any preceding claim.

For the Applicants,
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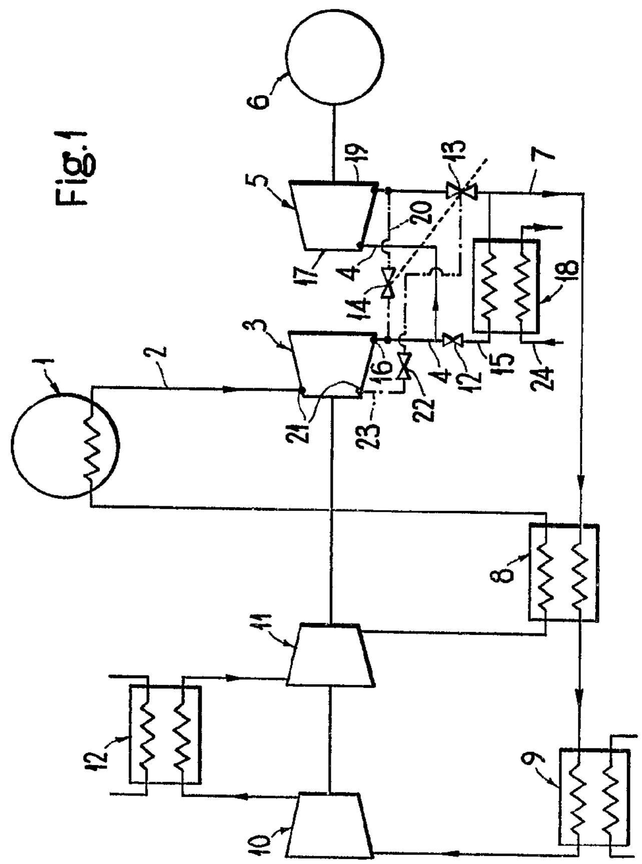

Fig. 1

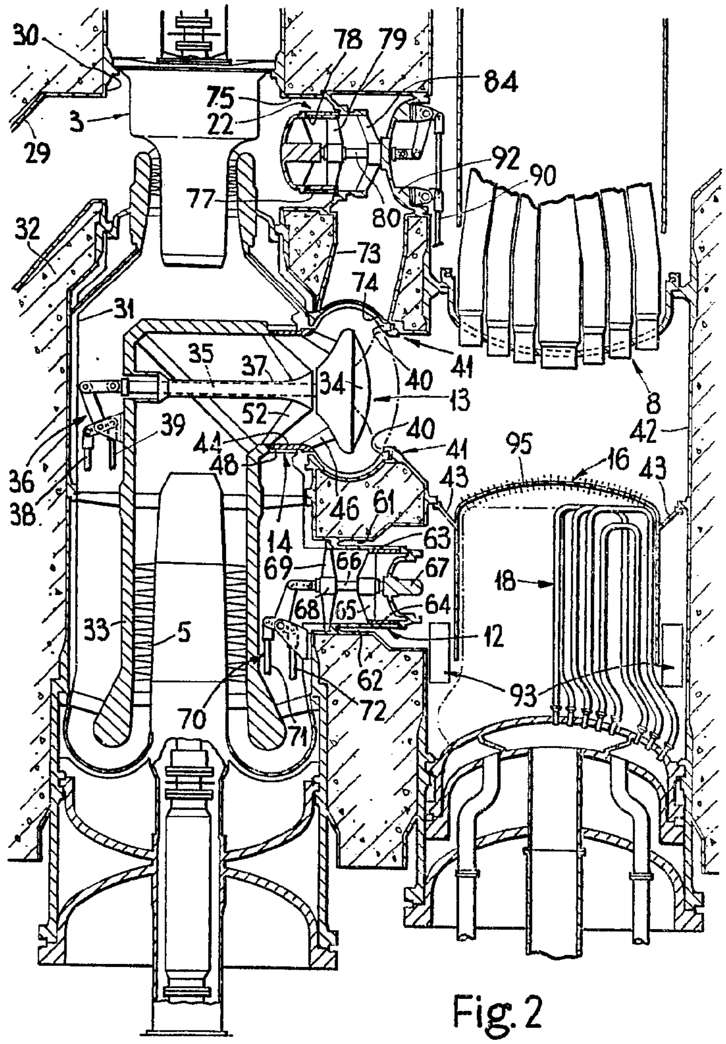
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Fig. 2

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Sheet 3

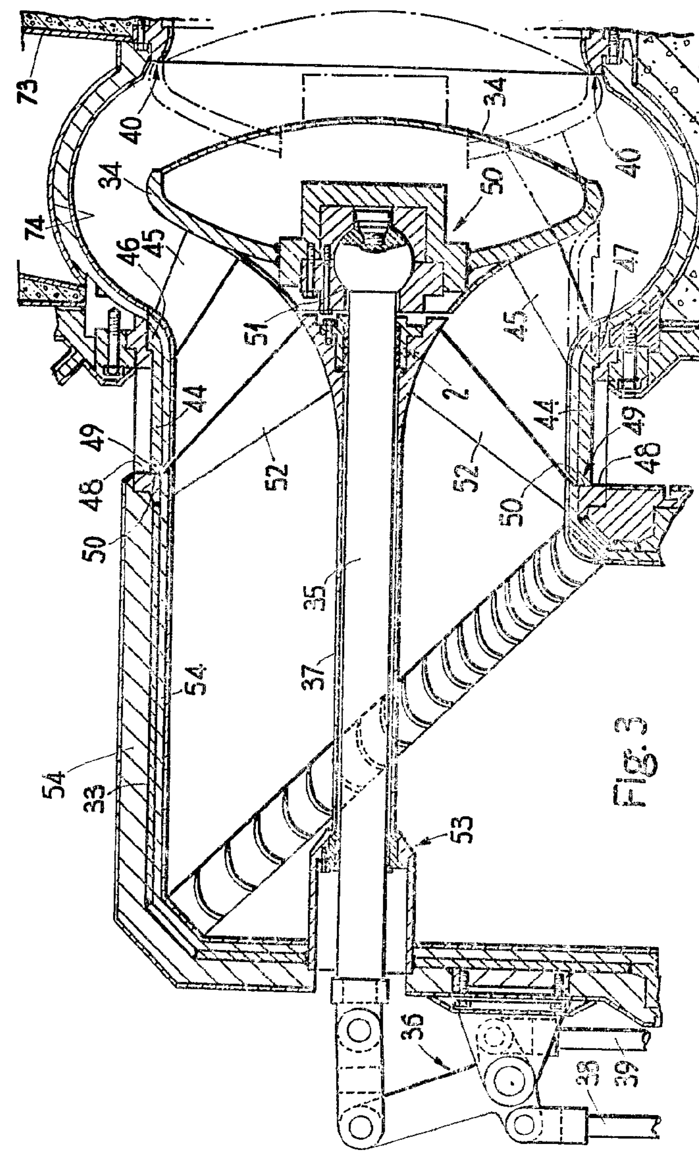

FIG. 3

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Sheet 4

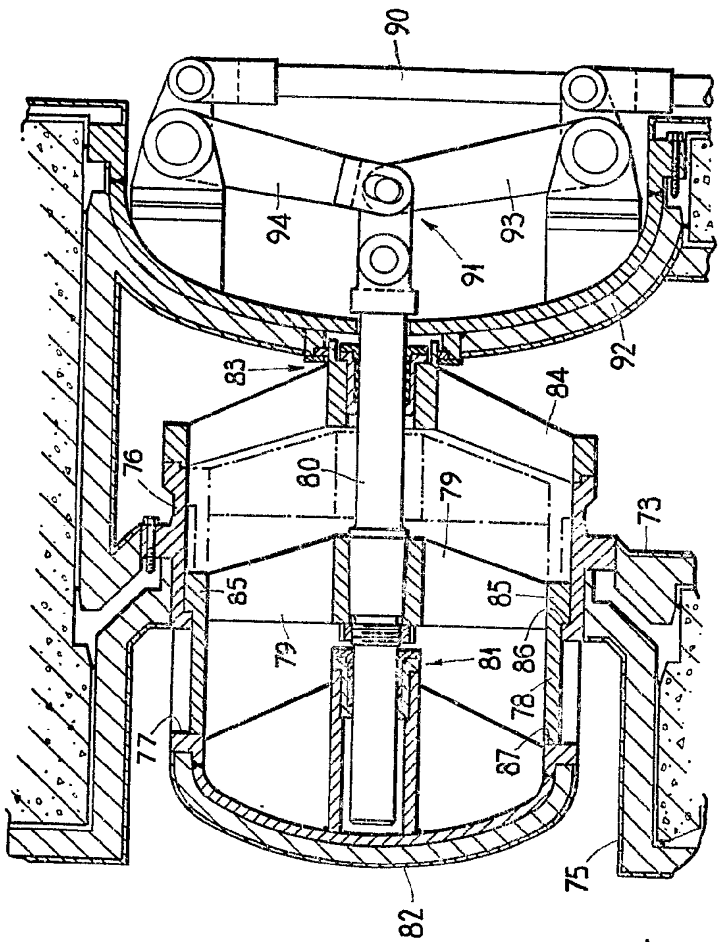

Fig. 4